The First Run II Measurement of the W Boson Mass by CDF

University of Oxford

People involved:

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Chris Hays (Electroweak Convenor)

Pete Renton (Chair of CDF committee overseeing the analysis)

Particle Physics Seminar Hilary Term

February 27th, 2007
Outline

1. Motivation
2. W Production at the Tevatron
3. Analysis Strategy
4. Detector Calibration
   - Momentum Scale
   - Energy Scale
   - Recoil
5. Event Simulation
6. Results
7. Conclusions
• 1930’s: Fermi explains nuclear $\beta$-decay as 4-point interaction

• 1960’s: Glashow, Weinberg and Salam
  → unify electromagnetic and weak interaction
  → explain interaction by exchange of massive vector bosons

• Became foundation of the Standard Model
• W boson mass is fundamental parameter
Introduction

- Derive W mass from precisely measured electroweak quantities

\[ m_W^2 = \frac{\pi \alpha_{em}}{\sqrt{2} G_F \sin^2 \theta_W (1 - \Delta r)} \]

- where \( M_W = M_Z \cos \theta_W \)

- \( \alpha_{EM}(M_Z) = 1/127.918(18) \)

- \( G_F = 1.16637(1) \times 10^{-5} \text{ GeV}^{-2} \)

- \( M_Z = 91.1876(21) \text{ GeV} \)

- \( \Delta r: \mathcal{O}(1\%) \) radiative corrections dominated by tb and Higgs loop
## Measured Top Mass

Top mass now measured to 2.1 GeV

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Mass (GeV)</th>
<th>(stat)</th>
<th>(syst)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D0 Dilepton</td>
<td>178.1 ± 6.7 ± 4.8</td>
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<tr>
<td>(L = 370 pb⁻¹)</td>
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<tr>
<td>D0 Lepton+Jets</td>
<td>170.3 ± 2.5 ± 3.8</td>
<td></td>
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<tr>
<td>(L = 370 pb⁻¹)</td>
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</tr>
<tr>
<td>CDF Dilepton</td>
<td>164.5 ± 3.9 ± 3.9</td>
<td></td>
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<tr>
<td>(L = 1030 pb⁻¹)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CDF Lepton+Jets</td>
<td>170.9 ± 1.6 ± 2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(L = 940 pb⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDF All hadronic</td>
<td>174.0 ± 2.2 ± 4.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(L = 1020 pb⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Best Tevatron Run II (°Preliminary)**

**Tevatron July'06**

(CDF+D0 Run II Average)
Motivation

Current top mass uncertainty 1.2% (2.1 GeV) → contributes 0.016% (13 MeV) to $\delta M_W$

Current W mass uncertainty 0.036% (29 MeV)

- Progress on W mass uncertainty now has the biggest impact on Higgs mass constraint
- With improved precision also sensitive to possible exotic radiative corrections
Predicted Higgs mass from W loop corrections:
\[ m_H = 85^{+39}_{-28} \text{ GeV} \] (<166 GeV at 95% CL)

Direct search from LEP II: \( m_H > 114.4 \)
Analysis Strategy
Tevatron Collider

- Tevatron is a proton antiproton collider with ~1 TeV per beam
- Currently the only place in the world where W and Z bosons can be produced directly
- 36 p and pbar bunches, 396 ns between bunch crossing, $E_{CM}=1.96$ TeV
Quark-antiquark annihilation dominates (80%)

precise charged lepton measurement is the key (achieved ~0.03%)

Recoil measurement allows inference of neutrino $E_T$ (restricted to $u<15$ GeV)

Combine information into transverse mass $m_T$:

$$m_T = \sqrt{2 p_T^l p_T^\nu (1 - \cos \phi_{lv})}$$
W/Z Boson Production at the Tevatron

- Initial state QCD radiation O(10 GeV) appears as soft “hadronic recoil” in calorimeter
- Pollutes W mass information *fortunately* $p_T^W \ll M_W$

- Can use $Z \rightarrow ll$ decays to calibrate recoil model
$\sigma(W \rightarrow l\nu) = 2775 \text{ pb}$

$\sigma(Z \rightarrow ll) = 254.9 \text{ pb}$

From the high $p_T$ lepton triggers ($p_T > 18 \text{ GeV}$)

After event selection

(l, $\nu$ $E_T > 30 \text{ GeV}$)

51,128 $W \rightarrow \mu\nu$ candidates

63,964 $W \rightarrow e\nu$ candidates

4,960 $Z \rightarrow \mu\mu$ candidates

2,919 $Z \rightarrow ee$ candidates
**Measurement Strategy**

W mass is extracted from transverse mass, transverse momentum and transverse missing energy distribution.

**Detector Calibration**
- Tracking momentum scale
- Calorimeter energy scale
- Recoil

**Fast Simulation**
- NLO event generator
- Model detector effects

**W Mass templates**

Data

Binned likelihood fit

W Mass

+ Backgrounds

81 GeV

80 GeV
$W$ Mass Measurement

$m_T$
- Insensitive to $p_T^W$ to 1st order
- Reconstruction of $p_T^\nu$ sensitive to hadronic response and multiple interactions

$p_T$
- Less sensitive to hadronic response modeling
- Sensitive to $W$ production dynamics
CDF Detector

- Silicon tracking detectors
- Central drift chambers (COT)
- Solenoid Coil
- EM calorimeter
- Hadronic calorimeter
- Muon scintillator counters
- Muon drift chambers
- Steel shielding
Tracking Momentum Scale Calibration
Tracker Alignment

- Internal alignment is performed using a large sample of cosmic rays → Fit hits on both sides to one helix
- Determine final track-level curvature corrections from electron-positron E/p difference in W → eν decays

- Statistical uncertainty of track-level corrections leads to systematic uncertainty
  \[ \Delta M_W = 6 \text{ MeV} \]
Mass Measurements

- Template mass fits to $J/\Psi \rightarrow \mu \mu$, $\Upsilon \rightarrow \mu \mu$, $Z \rightarrow \mu \mu$ resonances

- Fast simulation models relevant physics processes
  - internal bremsstrahlung
  - ionization energy loss
  - multiple scattering

- Simulation includes event reconstruction and selection

- First principle simulation of tracking

- Detector material model
  - Map energy loss and radiation lengths in each detector layer
    (3D lookup table in $r$, $\varphi$ and $z$)

- Overall material scale determined from data
Momentum Scale $J/\Psi$

- $J/\psi$ mass independent of $p_T$
- Slope affected by energy loss modelling
- Measurement dominated by systematic uncertainties → QED and energy loss model

$\Delta p/p = (-1.536 \pm 0.088) \times 10^{-3}$

$\chi^2$/dof = 17 / 22

default material scaled to 0.94 to tune energy loss

$J/\psi \rightarrow \mu\mu$ data

Scale correction = $(-1.64\pm0.01_{\text{stat}}\pm0.06_{\text{slope}}) \times 10^{-3}$
• Y provide invariant mass intermediate between J/Ψ and Z’s

• Y are all primary tracks can be beam-constrained, like W tracks

• Test beam constraint by measuring mass using unconstrained tracks

• Correct by half the difference between fits and take corrections as systematic uncertainty
Δp/p = (-1.50 ± 0.20) x 10^{-3}

- **Systematic uncertainties:**

<table>
<thead>
<tr>
<th>Source</th>
<th>J/ψ (x10^{-3})</th>
<th>Υ (x10^{-3})</th>
<th>Common (x10^{-3})</th>
</tr>
</thead>
<tbody>
<tr>
<td>QED and energy loss model</td>
<td>0.20</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>Magnetic field nonuniformities</td>
<td>0.10</td>
<td>0.12</td>
<td>0.10</td>
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<tr>
<td>Beam constraint bias</td>
<td>N/A</td>
<td>0.06</td>
<td>0</td>
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<tr>
<td>Ionizing material scale</td>
<td>0.06</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>COT alignment corrections</td>
<td>0.05</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Fit range</td>
<td>0.05</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>pT threshold</td>
<td>0.04</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Resolution model</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Background model</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>World-average mass value</td>
<td>0.01</td>
<td>0.03</td>
<td>0</td>
</tr>
<tr>
<td>Statistical</td>
<td>0.01</td>
<td>0.06</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.25</strong></td>
<td><strong>0.21</strong></td>
<td><strong>0.17</strong></td>
</tr>
</tbody>
</table>
Momentum Scale Cross-Check

Apply momentum scale to Z sample

$Z \rightarrow \mu\mu$

$M_Z = (91184 \pm 43) \text{ MeV}$

$\chi^2/\text{dof} = 32/30$

Z mass in good agreement with PDG $(91188\pm2 \text{ MeV})$

All momentum scales consistent

$\Delta M_W = 17 \text{ MeV}$
EM Calorimeter Scale Calibration
Calorimeter Energy Calibration

- Transfer momentum calibration to calorimeter using $E/p$ distribution of electrons from $W$ decay by fitting peak of $E/p$

- Additional physics effects beyond those for muon tracks
  - photon radiation and conversion
Full Electron Simulation

- Response and resolution in EM calorimeter
- Energy loss into hadronic calorimeter
- Energy loss in solenoid
- Track reconstruction in outer tracker
- Bremsstrahlung and conversions in silicon

Electromagnetic Calorimeter

SVX II 5 LAYERS

INTERMEDIATE SILICON LAYERS

END WALL HADRON CAL.

END PLUG HADRON CAL.

COT

SOLENOID
Energy Scale Calibration

- Calibrate calorimeter energy with peak of $E/p$ distribution
- Energy Scale $S_E$ set to $S_E = 1 \pm 0.00025^{\text{stat}} \pm 0.00011^{\text{X0}} + -0.00021^{\text{Tracker}}$
- Setting $S_E$ to 1 using $E/p$ calibration

Calorimeter Energy $<$ Track Momentum:
Energy loss in Hadronic calorimeter

Calorimeter Energy $>$ Track Momentum:
Energy loss in tracker

CDF II preliminary $\int Ldt \approx 200 \text{ pb}^{-1}$

$W \rightarrow e\nu$

$S_E = 1 \pm 0.00025^{\text{stat}}$

$\chi^2/\text{dof} = 17 / 16$

Data
Simulation
Consistency of Radiative Material Model

- Excellent description of E/p tail
- Radiative material tune factor: \( S_{\text{mat}} = 1.004 \pm 0.009_{\text{stat}} \pm 0.0002_{\text{bkg}} \)
- Z mass reconstructed from electron track momenta

Data
Simulation

geometry confirmed: \( S_{\text{mat}} \) independent of \( |\eta| \)

Measured value in good agreement with PDG
• Fit Z Mass using scale from E/p calibration
• Measure non-linearity through E/p fits in bins of E_T in W→eν and Z→ee data and apply correction to simulation

\[ \Delta M_W = 30 \text{ MeV} \]

Z Mass Cross-Check and Final Energy Scale

Z→ee

\[ M_Z = (91190 \pm 67_{\text{stat}}) \text{ MeV} \]

\[ \chi^2/\text{dof} = 34/38 \]

Z mass in good agreement with PDG (91187±2 MeV)
Detector Resolutions

- Tracking resolution parametrized in fast Monte Carlo by
  - Drift chamber hit resolution $\sigma_h = 150 \pm 3_{\text{stat}} \ \mu m$
  - Beamspot size $\sigma_b = 39 \pm 3_{\text{stat}} \ \mu m$
  - Tuned on widths of $Z \rightarrow \mu \mu$ and $Y \rightarrow \mu \mu$ distribution
    $$\Delta M_W = 3 \text{ MeV}$$

- Electron cluster resolution parametrized by $13.5\% / \sqrt{E_T} \oplus \kappa$
  - primary electron constant term: $\kappa = 0.89 \pm 0.15_{\text{stat}} \%$
  - secondary photon resolution: $\kappa = 8.3 \pm 2.2_{\text{stat}} \%$

- Tuned on the widths of the $E/p$ peak and $Z \rightarrow ee$ peak (selecting radiative electrons)
  $$\Delta M_W = 9 \text{ MeV}$$
Hadronic Recoil Model
Hadronic Recoil Definition

Recoil definition:
→ Vector sum over all calorimeter towers, excluding:
  - lepton towers
  - towers near beamline ("ring of fire")

• Lepton removal also removes underlying event
  → Need to measure recoil under lepton

• Recoil under lepton depends on lepton tower definition
Lepton Removal

- Estimate removed recoil energy using towers separated in $\Phi$
- Model tower removal in simulation

**Muon Electromagnetic $E_T$ (MeV)**

<table>
<thead>
<tr>
<th>Tower $\Delta \eta$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower $\Delta \phi$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>27</td>
<td>27</td>
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<tr>
<td>$\Delta M_W$ = 5 MeV</td>
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</tbody>
</table>

**Electron Electromagnetic $E_T$ (MeV)**

<table>
<thead>
<tr>
<th>Tower $\Delta \eta$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower $\Delta \phi$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>29</td>
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<td>31</td>
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<td>27</td>
<td>28</td>
<td>27</td>
<td>28</td>
<td>27</td>
<td>28</td>
</tr>
<tr>
<td>$\Delta M_W$ = 8 MeV</td>
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</tbody>
</table>

Muons: Remove 3 towers (MIP)  
Electrons: Remove 7 towers  
keystone (shower)
Recoil momentum vector \( u \) has two components:

- Soft spectator interaction component, randomly oriented
  - modelled using minimum bias data with tuneable magnitude

- A hard ‘jet’ component, directed opposite the boson \( p_T \)
  - \( p_T \) dependent response and resolution parametrization
  - Hadronic response \( R=(u_{\text{meas}}/u_{\text{true}}) \)
  - \( R \) parametrized as a logarithmically increasing function of boson \( p_T \)

---

**Motivated by Z boson data**
Hadronic Recoil Response Calibration

- Project vector sum of $p_T^{(ll)}$ and $u$ on orthogonal axes defined by lepton directions
- Use Z balancing to calibrate recoil energy scale
- Mean and RMS of projections as a function of $p_T^{(ll)}$ provide information for model parameters

Hadronic model parameters tuned by minimizing $\chi^2$ between data and simulation

$\Delta M_W = 9 \text{ MeV}$
Resolution at low $p_T(Z)$ dominated by underlying event

Resolution at high $p_T(Z)$ dominated by jet resolution

$\Delta M_W = 7\, \text{MeV}$
Recoil Model Checks

• Apply model to W sample to check recoil model from Z’s
• Recoil projection along lepton direction \( u_{||} \)

→ directly affects \( m_{T} \) fits
→ Sensitive to: lepton removal, efficiency model, scale, resolution, W decay

• Recoil projection perpendicular to lepton direction \( u_{\perp} \)

→ Sensitive to resolution model
Recoil Model Checks

- Recoil distribution
  → Sensitive to recoil scale resolution and boson $p_T$

- Recoil model validation plots confirm the consistency of the model
Signal Simulation and Template Fitting

- All signals simulated using a fast simulation
  - Generate finely-spaced templates as a function of fit variable
  - perform binned maximum-likelihood fits to the data

- Custom fast simulation makes smooth, high statistics templates
  - provides analysis control over key components of simulation

- We will extract the W mass from six kinematic distributions:
  \( m_T, p_T \) and \( E_T \) for muon and electron channel
Generator-level Signal Simulation

- Generator-level input for W&Z simulation provided by RESBOS [Balazs et al. PRD56, 5558 (1997)]

- Radiative photons generated according to energy vs angle lookup table from WGRAD [Baur et al. PRD59, 013002 (1998)]
  - Simulate FSR (ISR, photons off the propagator, < 5 MeV)
  - Apply 10% correction for 2nd photon
[Calame et al. PRD69, 037301 (2004)]
  and take 5% systematic uncertainty \( \Delta M_W = 11 \pm 12 \) MeV for e (\( \mu \))
Boson $p_T$ Model

- Model boson $p_T$ using RESBOS generator

- Non-pertubative regime at low $p_T$ parametrized with $g_1, g_2, g_3$ parameters

- $g_2$ parameter determines position of peak in $p_T$ distribution

- Measure $g_2$ with Z boson data (other parameters negligible)

- Find: $g_2 = 0.685 \pm 0.048$

\[ \Delta M_W = 3 \text{ MeV} \]
Parton Distribution Functions

- Affect W kinematic lineshape through acceptance cuts (only use $|\eta|<1$)
- We use CTEQ6M as the default
- Use CTEQ6 ensemble of 20 ‘uncertainty PDFs’:
  - 20 free parameters in global fit
  - compute $\delta M_W$ contribution from each error PDF
- Using CTEQ prescription and interpreting ensemble as 90% CL

\[ \Delta M_W = 11 \text{ MeV} \]

- Cross-check: Fitting MC sample generated with MRST2003 with default CTEQ6M template yields a 8 MeV shift in W mass
Backgrounds

- Backgrounds have very different lineshapes compared to W signal
  - distributions are added to template
  - QCD measured with data
  - EWK predicted with Monte Carlo

<table>
<thead>
<tr>
<th>Background</th>
<th>% (Muons)</th>
<th>% (Electrons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hadronic Jets</td>
<td>0.1±0.1</td>
<td>0.25±0.15</td>
</tr>
<tr>
<td>Decay in Flight</td>
<td>0.3±0.2</td>
<td>-</td>
</tr>
<tr>
<td>Cosmic Rays</td>
<td>0.05±0.05</td>
<td>-</td>
</tr>
<tr>
<td>Z→ll</td>
<td>6.6±0.3</td>
<td>0.24±0.04</td>
</tr>
<tr>
<td>W→τν</td>
<td>0.89±0.02</td>
<td>0.93±0.03</td>
</tr>
</tbody>
</table>

$$\Delta M_W = 8 \ (9) \ MeV \ \text{for e} \ (\mu)$$
W Boson Mass Fits
Transverse Mass Fit (Muons)

CDF II preliminary

\[ \int L \, dt \approx 200 \text{ pb}^{-1} \]

\[ M_W = \left(80349 \pm 54_{\text{stat}}\right) \text{ MeV} \]

\[ \chi^2/\text{dof} = 59/48 \]

- Data
- Simulation
Muon and Electron combined: $M_W = 80417 \pm 48 \text{ MeV}$ $P(\chi^2) = 7\%$
Transverse Momentum Fit (Muons)

CDF II preliminary

\[ \int L \, dt \approx 200 \, \text{pb}^{-1} \]

\[ M_W = (80321 \pm 66_{\text{stat}}) \, \text{MeV} \]

\[ \chi^2/\text{dof} = 72 / 62 \]
Transverse Energy Fit (Electrons)

Muon and Electron combined: $M_W = 80388 \pm 59$ MeV $P(\chi^2) = 18\%$
**Missing Transverse Energy Fit (Muons)**

CDF II preliminary

\[ \int L \, dt \approx 200 \text{ pb}^{-1} \]

\[ M_W = (80396 \pm 66_{\text{stat}}) \text{ MeV} \]

\[ \chi^2/\text{dof} = 44 / 62 \]

- Data
- Simulation
Muon and Electron combined: $M_W = 80434 \pm 65$ MeV $P(\chi^2) = 43\%$
# Systematic Uncertainty

## Systematic uncertainty on transverse mass fit

<table>
<thead>
<tr>
<th>CDF II preliminary</th>
<th>L = 200 pb⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>( m_T ) Uncertainty [MeV]</td>
<td>Electrons</td>
</tr>
<tr>
<td>Lepton Scale</td>
<td>30</td>
</tr>
<tr>
<td>Lepton Resolution</td>
<td>9</td>
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<tr>
<td>Recoil Scale</td>
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<tr>
<td>Recoil Resolution</td>
<td>7</td>
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<tr>
<td>( u_{ll} ) Efficiency</td>
<td>3</td>
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<tr>
<td>Lepton Removal</td>
<td>8</td>
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<td>Backgrounds</td>
<td>8</td>
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<tr>
<td>( p_T(W) )</td>
<td>3</td>
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<td>PDF</td>
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<td>QED</td>
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<tr>
<td>Total Systematic</td>
<td>39</td>
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<tr>
<td>Statistical</td>
<td>48</td>
</tr>
<tr>
<td>Total</td>
<td>62</td>
</tr>
</tbody>
</table>

⇒ Combined Uncertainty: 48 MeV for 200 pb⁻¹
Results

- Combining all six mass fits yields:

\[ M_W = 80413 \pm 48 \text{ MeV (stat+syst)}, \ P(\chi^2) = 44\% \]

- New CDF result is the world’s most precise single measurement

  - World average increases: 80392 to 80398 MeV
  - Uncertainty reduced ~15% (29 to 25 MeV)
Previous $M_W$ vs $M_{\text{top}}$
Winter 2007

Experimental errors 68% CL:

- LEP2/Tevatron (today)

Updated $M_W$ vs $M_{top}$

- $M_W$ vs $M_{top}$
- $M_H = 114$ GeV
- $M_W = 400$ GeV

SM
- MSSM
- light SUSY
- heavy SUSY
- both models

Heinemeyer, Hollik, Stockinger, Weber, Weiglein '06
Standard Model Higgs Constraint

• Previous SM Higgs fit:
  - $M_H = 85^{+39}_{-28}$ GeV
  - $M_H < 166$ GeV (95% CL)
  - $M_H < 199$ GeV (95% CL) Including LEPII direct exclusion

• Updated preliminary SM Higgs fit:
  - $M_H = 80^{+36}_{-26}$ GeV (M. Grünewald, private communication)
  - $M_H < 153$ GeV (95% CL)
  - $M_H < 189$ GeV (95% CL) Including LEPII direct exclusion
Progress since 1995

2007 direct $m_t$ and $m_w$

2007 indirect $m_t$ and $m_w$

1995 indirect $m_t$ and $m_w$

1995 direct $m_t$ and $m_w$
Projection

- Projection from previous Tevatron measurements
Summary

• W boson mass remains a very interesting parameter to measure with increasing precision

• CDF Run II measurement is the most precise single measurement

\[ M_W = 80413 \pm 34 \pm 34 \text{ MeV} \]
\[ = 80413 \pm 48 \text{ MeV (preliminary)} \]

• New preliminary Higgs constraint \( M_H = 80^{+36}_{-26} \text{ GeV} \)
  (previous \( M_H = 85^{+39}_{-28} \text{ GeV} \))

→ Mass has moved further in the directly excluded region

Looking forward:

→ Expect \( \Delta M_W < 25 \text{ MeV} \) with 1.5 fb\(^{-1} \) already collected by CDF
Backup Slides
# Systematic Uncertainty

<table>
<thead>
<tr>
<th>CDF II preliminary</th>
<th>L = 200 pb⁻¹</th>
<th>CDF II preliminary</th>
<th>L = 200 pb⁻¹</th>
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<tbody>
<tr>
<td>p_T Uncertainty [MeV]</td>
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<td>MET Uncertainty [MeV]</td>
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<tr>
<td>Lepton Scale</td>
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<td>Lepton Resolution</td>
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<tr>
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<td>Backgrounds</td>
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<tr>
<td>p_T(W)</td>
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<tr>
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<td>Statistical</td>
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<tr>
<td>Total</td>
<td>73</td>
<td>Total</td>
<td>79</td>
</tr>
</tbody>
</table>

Oliver Stelzer-Chilton - Oxford
Consistency Checks of Results

- Use BLUE method to combine results and check consistency
- List of obtained $\chi^2$ and probabilities for several combinations:
  - two transverse mass fits: $\chi^2$/dof = 3.2/1, prob = 7%
  - charged lepton fits: $\chi^2$/dof = 1.8/1, prob = 18%
  - two MET fits: $\chi^2$/dof = 0.6/1, prob = 43%
  - all three fits for electrons: $\chi^2$/dof = 1.4/2, prob = 49%
  - all three fits for muons: $\chi^2$/dof = 0.8/2, prob = 69%
  - all six fits, both channels: $\chi^2$/dof = 4.8/5, prob = 44%
Signed $\chi$

CDF II preliminary

$\int L \, dt \approx 200 \, \text{pb}^{-1}$
### Tevatron Run I Uncertainties

<table>
<thead>
<tr>
<th></th>
<th>CDF $\mu$</th>
<th>CDF e</th>
<th>DØ e</th>
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<tr>
<td><strong>Total</strong></td>
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<td>113</td>
<td>84</td>
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Energy Loss Model

- Use GEANT to parametrize energy loss in solenoid and leakage into hadronic calorimeter
- Energy loss in hadronic calorimeter
- Relevant for E/p lineshape
Measurement of EM Calorimeter Non-Linearity

- Perform $E/p$ fit-based calibration in bins of electron $E_T$
- Parametrize non-linear response as $S_E = 1 + \xi (E_T/\text{GeV}^{-39})$
- Apply energy dependent scale to simulated electron and photon
- Tune $W$ and $Z$ data: $\xi = (6 \pm 7) \times 10^{-5}$
Momentum Scale Calibration

Central Outer Tracker: Open-cell drift chamber

- Use clean sample of cosmic rays for cell-by-cell internal alignment
- Fit COT hits on both sides simultaneously to a single helix
- Measure cell displacements
Alignment Example

Final relative alignment of cells ~5μm (initial alignment ~50μm)
**Consistency Check of COT Alignment**

- Fit separate helices to cosmic ray tracks on each side
- Compare track parameters of the two tracks
- Measure of track parameter bias

Curvature:

![Graph showing curvature analysis](image)

**False curvature smaller than 0.1% for 40 GeV track, over the length of the COT**
Outlook

What is the Higgs mass?